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PENSOFT

New records of *Kallstroemia tribuloides* (Mart.) Steud. (Zygophyllaceae) in Rio de Janeiro state, Brazil, after 136 years: a bioinvasion in progress?

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Abstract. We report the occurrence of *Kallstroemia tribuloides* (Mart.) Steud. in Rio de Janeiro, Brazil after 136 years. *Kallstroemia tribuloides* is adapted to open, sunny environments with a preference for sandy soils, which are typical drylands (e.g., the Caatinga biome) and Restingas. This species has attributes that may favor its expansion into newly environments, and its bioinvasive potential should not be overlooked. Thus, we strongly recommend that further studies monitor the spread of *K. tribuloides* on the Brazilian southeast coast, which can help in its control.

Keywords. Alien species, distribution expansion, ecology, rediscovery

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Introduction

The family Zygophyllaceae consists of 22 genera and about 285 species, which are distributed throughout drylands of the world with a few of them extending to neighboring ecosystems (Sheahan 2007). In Brazil, the family is represented by three native genera—*Bulnesia* Gay, *Gonopterodendron* (Griseb.) Godoy-Bürki, and *Kallstroemia* Scop.—and four species. *Kallstroemia* is the only genus with two species, *Kallstroemia maxima* (L.) Hook. and *Kallstroemia tribuloides* (Mart.) Steud. However, the identification of *K. maxima* in Brazil is dubious, as Brazilian vouchers apparently do not fit the species' description (Soares e Silva et al. 2014), and the natural range of *K. maxima* is in the western USA (Ribeiro 2023).

Kallstroemia tribuloides occurs in Argentina, Bolivia, and Brazil. In Brazil, the distribution of *K. tribuloides* is thought to be restricted to Caatinga biome. We report the expanding distribution of *K. tribuloides* in Brazilian territory and the possible implications of an incipient bioinvasion process, since the identification of potentially invasive alien species before their spreading over the landscape has long been a major goal (Hulme 2003).

Methods

The *Kallstroemia tribuloides* specimens reported here were found after casual identification of the first individuals on 6 March 2023 in an urban area recently altered by civil construction works (i.e., asphalting and paving), at Boqueirão, Saquarema, Rio de Janeiro state, Brazil.

Saquarema city is situated in the central coast of Rio de Janeiro state. Local vegetation is a mosaic of a very fragmented and disturbed remnants of Atlantic Rain Forest and Sandy Coastal Vegetation (Sá and Araujo 2009), named Restinga (Araujo 1992). The regional climate is classified as BSh, a variation of the Köppen-Geiger hot semi-arid climate, and factors such as the topography and the coastal upwelling of Cabo Frio

lead to a decrease in the rainfall (Bohrer 2009). Annual rainfall is about 800 mm (Ribeiro and Lima 2009) and falls mainly in October to March (Alvares et al. 2013).

Samples were deposited in the RBR Herbarium (Department of Botany, Federal Rural University of Rio de Janeiro). We used Soares e Silva's (2014) key to identify the specimens. After identification, we surveyed online herbaria databases: Virtual Herbarium of Plants and Fungi (speciesLink 2023) and Rio de Janeiro Botanical Garden Virtual Herbarium (Jabot RB 2023). They are the most comprehensive virtual database of herbaria specimens in Brazil and have continuously been updated. In both databases, we adopted a broad search initially using the family name (Zygophyllaceae).

Subsequently, we proceeded with data cleaning. First, the downloaded spreadsheets were merged, and we retained the useful fields: herbarium, taxonomic information, sampling location, geographic coordinates, collectors, and collection date. Second, we filtered the spreadsheet by country, keeping only the Brazilian records. After that, we checked and standardized all the scientific names. The Flora e Funga do Brasil (2023) and the World Flora Online (2023) websites were used to compare scientific names. Next we filtered the dataset for *Kallstroemia tribuloides* and determined if a voucher had geographic coordinates. We inferred geographic coordinates, based on the locality names, when coordinates not available in the data.

We mapped the current distribution of *K. tribuloides* in Brazil, based on our field collections and information from the virtual herbaria. Data preparations were carried out in R programming language (R Core Team 2023) using the following packages for each step: data cleaning, tidyverse (Wickham et al. 2019); inferring geographic coordinates from localities, tmaptools (Tennekes 2021); map making, geobr (Pereira and Gonçalves 2023), spatial (Dunnington 2022), and tmaptools (Tennekes 2021).

Results

***Kallstroemia tribuloides* (Mart.) Steud.**

Figure 1

New records. BRAZIL • Rio de Janeiro, Saquarema, Boqueirão; 22°55′55″S, 042°31′13″W; 1–10 m elev.; 07.III.2023; A.B.I. Santos 6 leg.; RBR58258 • same location; 22°55′44″S, 042°32′11″W; 1–10 m elev.; 07.III.2023; A.B.I. Santos 1 leg.; RBR58256 • Saquarema, Barra Nova; 22°55′36″S, 042°32′52″; 1–10 m elev.; 07.III.2023; A.B.I. Santos 5 leg.; RBR58257.

Description. Prostrate herb with radial growth. Branches with a dichotomous pattern of branching and a slight dilatation at the nodes. Leaves compound and opposite, paripinnate normally with 3–6 pairs of elliptical to lanceolate leaflets. Isolated, pedunculated, yellowish to orange flowers with five free sepals and five free petals. Androecium with 10 free stamens. Gynoecium with superior ovary with 10 locules. Tuberculated schizocarp fruit (Soares e Silva et al. 2014). Diaspore dispersal probably epizoochoric. Flower anthesis diurnal.

Distribution. We found 239 records of *K. tribuloides* in our survey of virtual herbaria. From 239 records, 204 originally included geographic coordinates. We inferred coordinates for the remaining 35 records. The records were mainly from Caatinga biome in northeastern Brazil. We found one record from Espírito Santo state, southeastern Brazil. In addition to our new records, we surprisingly found a very old record of *K. tribuloides* from Rio de Janeiro, which collected in 1877. We found two records from the Fernando de Noronha Archipelago, which is located off the northeastern Brazilian coast (Fig. 2). Our newly collected specimens were from urban areas (Fig. 1A, B), but we also detected individuals growing in the native Restinga vegetation on a nearby beach (Fig. 1C, D).

Discussion

Kallstroemia tribuloides is nearly entirely distributed in the Caatinga biome in Brazil. Prior to this study there were only two records outside the Northeast Region: one from Espírito Santo State, collected in 1972, and another from Rio de Janeiro state, collected in 1877. The record from 1877 is of historical interest, as it was made in the São Cristóvão neighborhood, which was home to the Brazilian royal family and the São Cristóvão Palace (Ferreira and Martins 2000). Hence, São Cristóvão attracted people from throughout the territory of Brazil (Ferreira and Martins 2000; Mafertan 2016). To our knowledge, we do not know if the species was brought intentionally. The 1877 record was made by the important botanist, Auguste François Marie Glaziou, who was in charge of the landscaping renovations around the palace in the 1860s and 1870s (Mafertan 2016). The exsiccate is stored in the herbarium of Muséum national d'Histoire naturelle, Paris, under the voucher number P03192077 (Vascular Plants (P) 2023). As our find is a century-old rediscovery, the arrival of *K. tribuloides* in Rio de Janeiro probably occurred multiple times; given the gap of 136 years and the unlikelihood of viable diaspores surviving for such a long period.

Kallstroemia tribuloides is recognized as a weedy plant of Brazilian semiarid regions, occurring in annual and perennial crops, gardens, and vacant lots and along roadsides (Lorenzi 2008). It is adapted to open and sunny environments, with a preference for sandy soils, which are typical conditions of drylands. In Brazil, drylands are mainly represented by the Caatinga biome (Pinheiro and Nair 2018). Drylands cover nearly 41% of the Earth's land surface and face a high risk of degradation worldwide (Cherlet et al. 2018). They are characterized by a scarcity of water, which affects both natural and managed ecosystems and acts as a filter for species composition. In this context, species of Zygophyllaceae have adaptations that allow them to colonize dryland environments: morphological and anatomical traits indicate that members of this family can use

Figure 1. Individuals of *Kallstroemia tribuloides* (Mart.) Steud. in Saquarema City, Rio de Janeiro state, Brazil. **A.** Plant in an urban environment. **B.** Close-up view of the opened flower. **C.** Plant in the restinga vegetation. **D.** Close-up view of the plant in restinga vegetation.

water efficiently (Yang and Furukawa 2006; Lauterbach et al. 2016), and Zygophyllaceae is one of 19 angiosperm families that use the C_4 photosynthetic pathway (Sage 2016). This set of traits offers an advantage in the extreme conditions of drought, sun, and high temperature (Christin et al. 2011).

The coastal region of Saquarema has some environmental attributes like drylands, such as poor, sandy soil, low rainfall, high insolation, and water shortages, of Restinga areas (Bohrer 2009; Ribeiro and Lima 2009). In nearby cities (Iguaba Grande to Cabo Frio and Búzios to Arraial do Cabo), the occurrence of a drier climate creates a peculiar environment where there is a trend of salinization and the presence of xeric vegetation, also called Caatinga (Ab'Saber 1977). This "Caatinga enclave" is similar to northeastern Caatinga and is maintained by its unique regional morphoclimate (Ibraimo et al. 2004).

Kallstroemia tribuloides has traits that may favor its expansion into new areas, and its bioinvasive potential should not be overlooked, particularly in the restinga environment. According to Richardson et al. (2000), non-native species are considered invasive when they sustain self-replacing and growing populations over several life cycles, reach large population densities, and spread far from their initial site of introduction. Bioinvasion frequently exerts substantial impacts on native communities and ecosystem functioning (Crystal-Ornelas and Lockwood 2020; Pyšek et al. 2020). Therefore, we believe it crucial to conduct further studies to monitor the spread of *K. tribuloides* on the Brazilian southeast coast, which will help with its control. It is

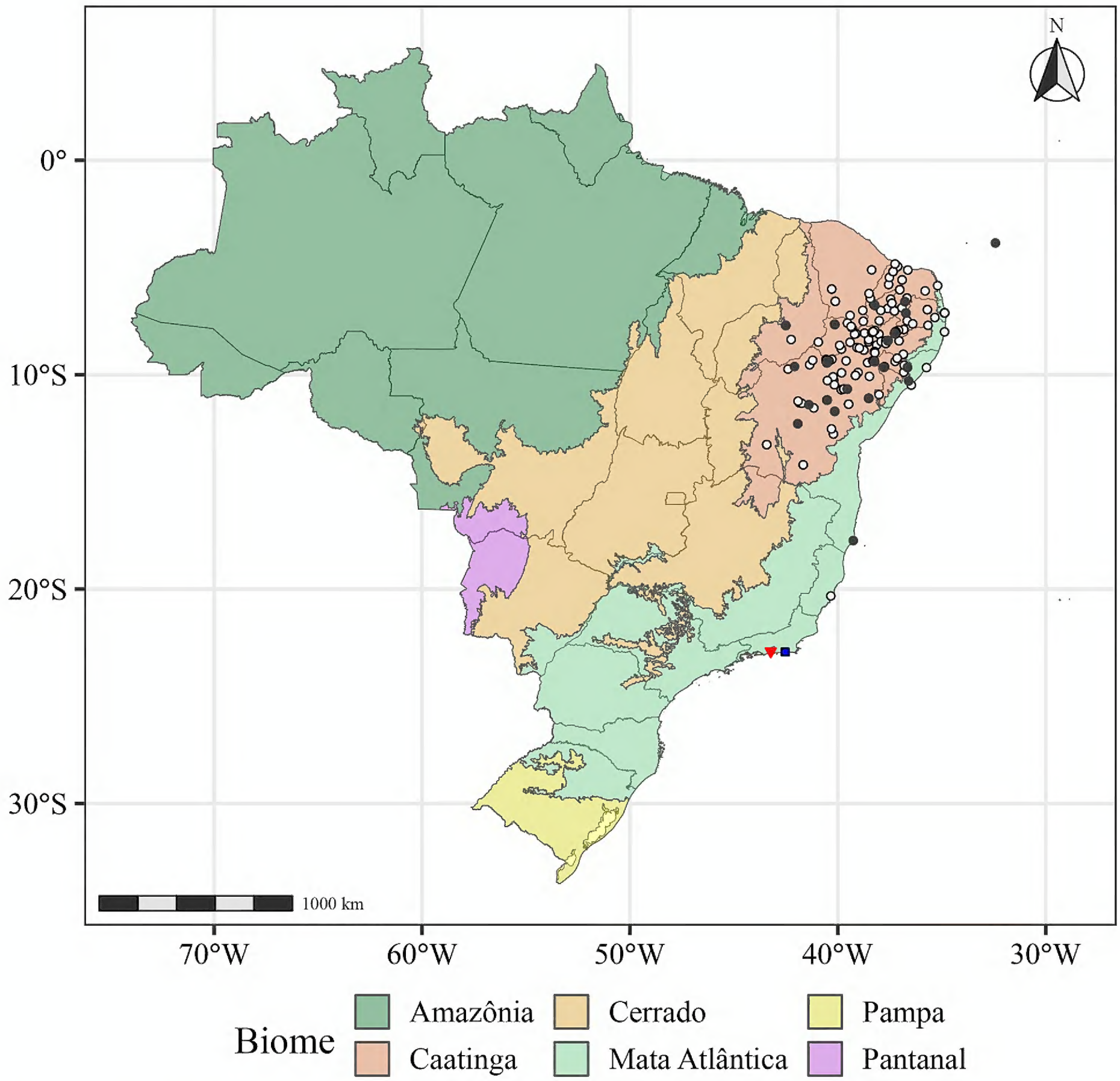

Figure 2. Distribution map of *Kallstroemia tribuloides* (Mart.) Steud. in Brazil, with biomes shown. White circles = previous records with geographic coordinates in original data. Dark gray circles = previous records with geographic coordinates inferred from locality data. Blue squares = new records. Red triangle = 1877 record from Rio de Janeiro state. Dark gray circle (mid-ocean) = record from the Fernando de Noronha Archipelago.

noteworthy that we have already found *K. tribuloides* in native restinga vegetation. This suggests that the process of bioinvasion is already underway.

Rio de Janeiro City and surrounding regions are predicted to suffer dramatic changes in climate in the next decades, which will include warming temperatures, decreases in total rainfall and its distribution, and reduced humidity (Barata et al. 2020). Our rediscovery of *K. tribuloides* after 136 years may be a sign that community and ecosystem changes are already underway, with climate change favoring species such as *K. tribuloides*, which has evolved in xeric environments.

Considering the *K. tribuloides* invasive potential, we propose some steps that can help to confirm this biological invasion and guide monitoring actions. Firstly, we suggest that comprehensive field surveys to detect occurrences of *K. tribuloides* in adjacent locations and neighboring cities should be undertaken to better recognize the extent of its distribution. The use of social media apps could be used for reporting its detection in new areas. Secondly, a population study of *K. tribuloides* would be useful to determine whether its population structure matches the criteria of an invasive species (Pyšek et al. 2004). Finally, once its invasiveness is confirmed, we recommend an investigation into the main type of propagule of *K. tribuloides*, and, with this information, establish adequate tools for controlling its spread.

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Author Contributions

Conceptualization: TAA, ABIS. Data curation: TAA, ABIS. Formal analysis: TAA. Investigation: TAA, ABIS. Methodology: TAA, ABIS. Resources: TAA, ABIS. Software: TAA, ABIS. Visualization: TAA, ABIS. Writing – original draft: TAA, ABIS. Writing – review and editing: TAA, ABIS.

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